Parameters of the two helium-rich subdwarfs in the short period binary PG1544+488

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Abstract

Helium-rich subdwarf B (He-sdB) stars form a small group of chemically peculiar, early-type, low-mass stellar remnants. They are thought to be formed either as a result of mergers of white dwarfs or by convective mixing of a helium white dwarf envelope after a late helium flash. PG1544+488 is the prototype of the He-sdB stars. It was serendipitously found to be short period binary (P ~ 0.5 day) comprising two helium-rich subdwarfs. In this poster we report physical parameters and orbital solution for the two helium-rich subdwarfs in PG1544+488 from optical spectra obtained over a period of three years. The physical parameters - effective temperature, surface gravity and helium abundances (by number) - for both subdwarfs were measured by fitting the observed spectra with LTE models using a chi-squared minimization procedure. The orbital solutions were obtained using radial velocities measured from the optical spectra. We also briefly discuss the implications of the discovery that PG1544+488 is a binary on our current understanding of the evolution of helium-rich subdwarf B stars and the possibility of a third formation channel for these stars involving a common-envelope in a close binary.

Introduction

- Subdwarf B (sdB) stars form the dominant population of faint blue blue stars ($m_B \sim 16$) in our galaxy and giant elliptical galaxies
- They are 0.5 M_{Sun} core helium-burning stars
- Believed to be progenitors of White Dwarfs
- Evolution has been the subject of much debate although binary evolution is though to play an important role
- sdB stars have spectra dominated by Hydrogen Balmer lines
- A small subset (~ 70) of hot subdwarf stars includes the helium-rich subdwarf B (or *He-sdB*) stars

Evolution models for helium-rich sdB stars

- Single star evolution

  Lanz et al. (2004) have argued that stars evolving with high mass loss on the red giant branch undergo a late helium core flash on the white dwarf cooling track leading to convective "flash mixing" of the envelope which then forms helium and carbon rich hot subdwarfs

- Binary merger model

  Iben & Tutukov (1986) suggested that the merger of two degenerate white dwarf can produce a hot subdwarf with depleted hydrogen atmosphere. Saio & Jeffery (2000) have more recently modelled WD mergers to explain the origin of EHe stars which then evolves into a helium-rich subdwarf

Previous analyses of PG1544+488

analyses carried out assuming a *single* star

T_{eff}	$\log g$	Reference
31 000	5.1	Heber et al. (1988) optical / UV spectra
34 000	5.1	Ahmad & Jeffery (2003) low resolution optical spectrum
32 100	[5.0]	Ahmad & Jeffery (2004) spectral energy distribution
36 000	6.0	Lanz et al. (2004) far ultraviolet spectra

Discovery of the He+He subdwarf binary!

- Spectroscopic observations of PG1544+488 obtained in 2003 May with the William Herschel Telescope (WHT) and the dual beam ISIS spectrograph showed strange line profiles in the neutral helium lines (Figs. 1 and 2)

- Visual examination indicated line splitting. Radial velocities of the two components were measured from optical blue and red spectra

- Archival TTAG FUSE spectra were re-extracted into time-resolved spectra. Radial velocity shifts were noted by cross-correlation between self template and theoretical spectra and show velocity variations similar to those seen in the optical spectra

- Preliminary orbital fitting of the radial velocities suggest that PG1544+488 is a shot period (~ 0.5 days) binary comprising two hot helium-rich subdwarf stars

Fig 1. Optical blue spectra

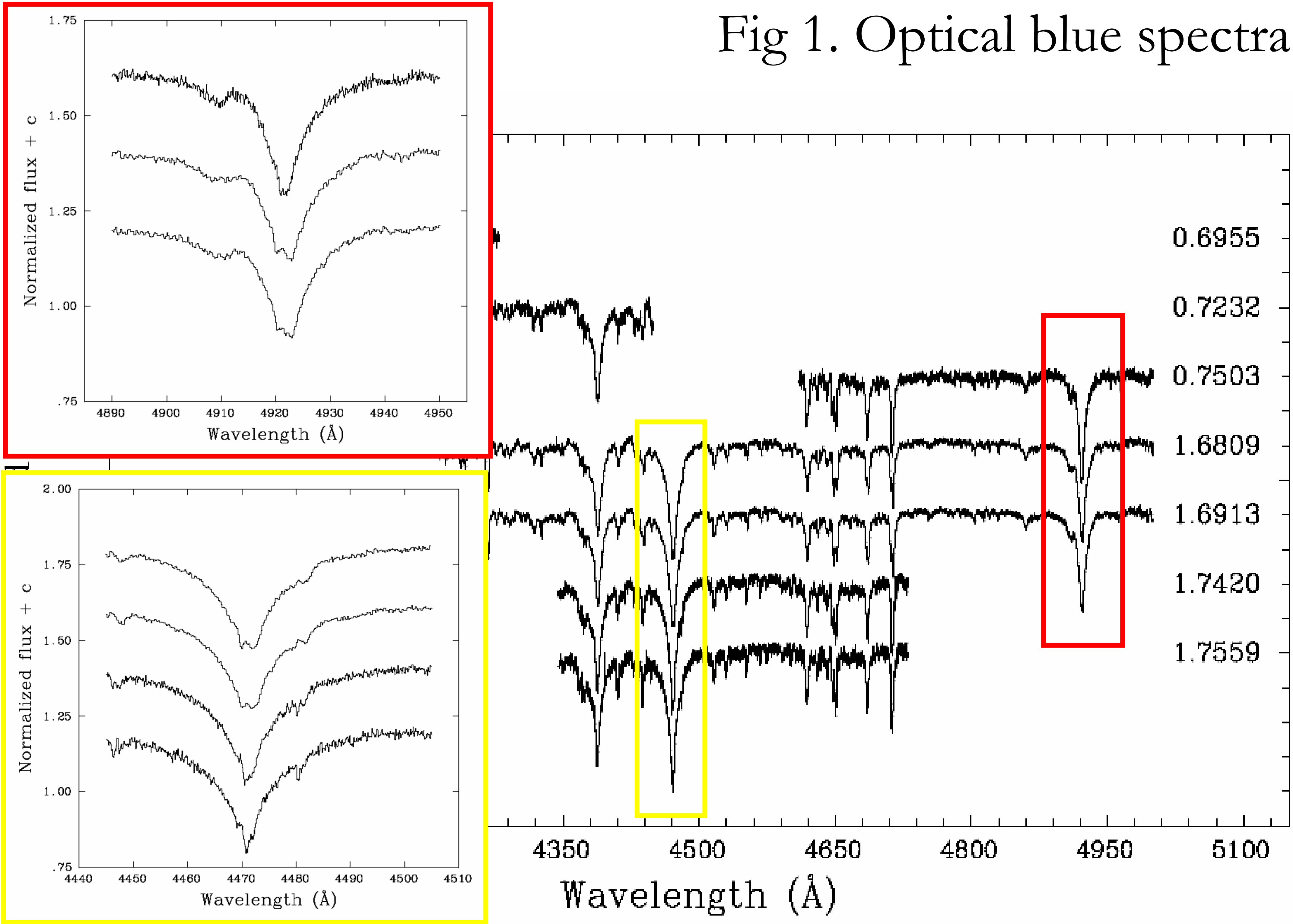


Fig 2. Optical red spectra

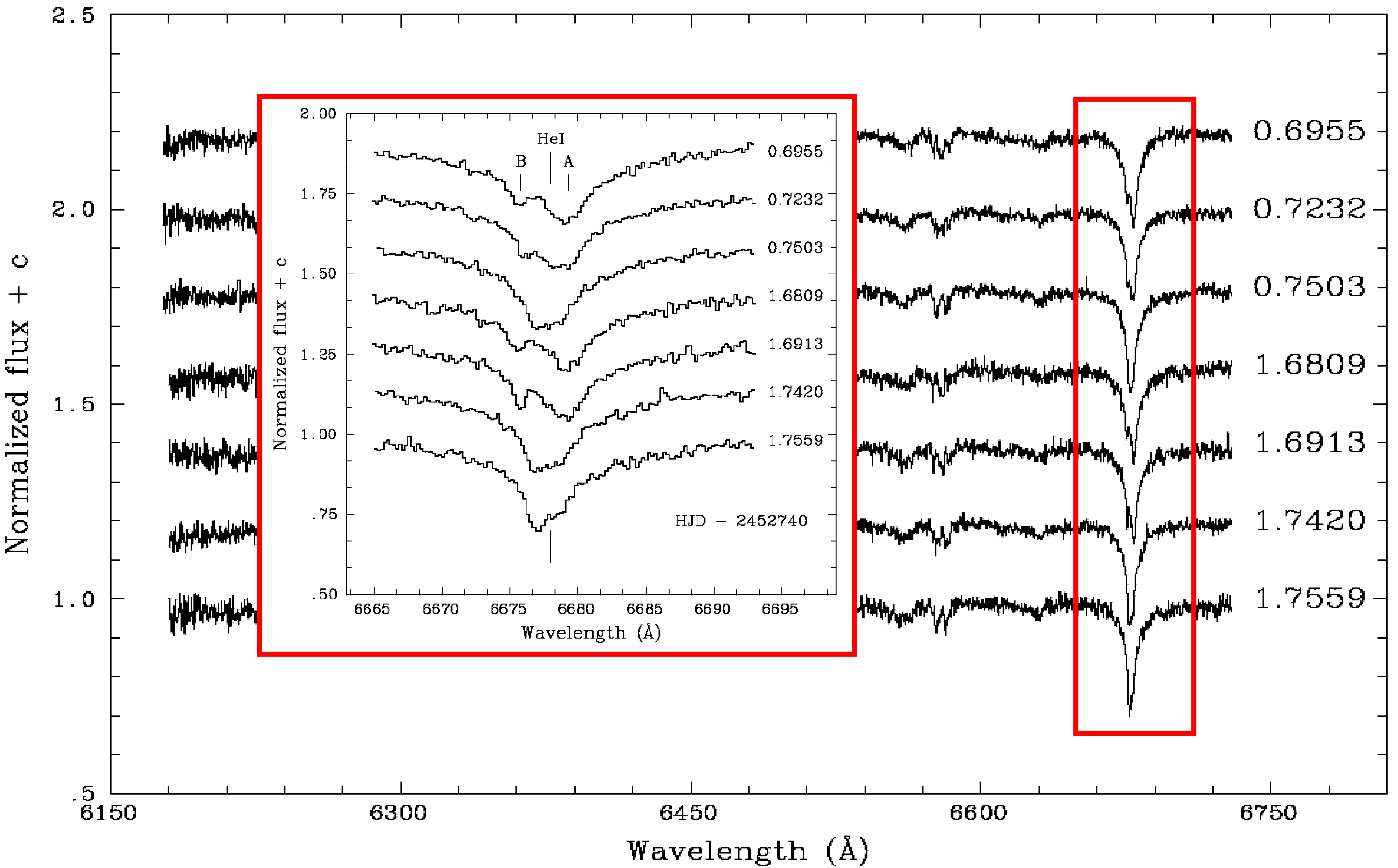
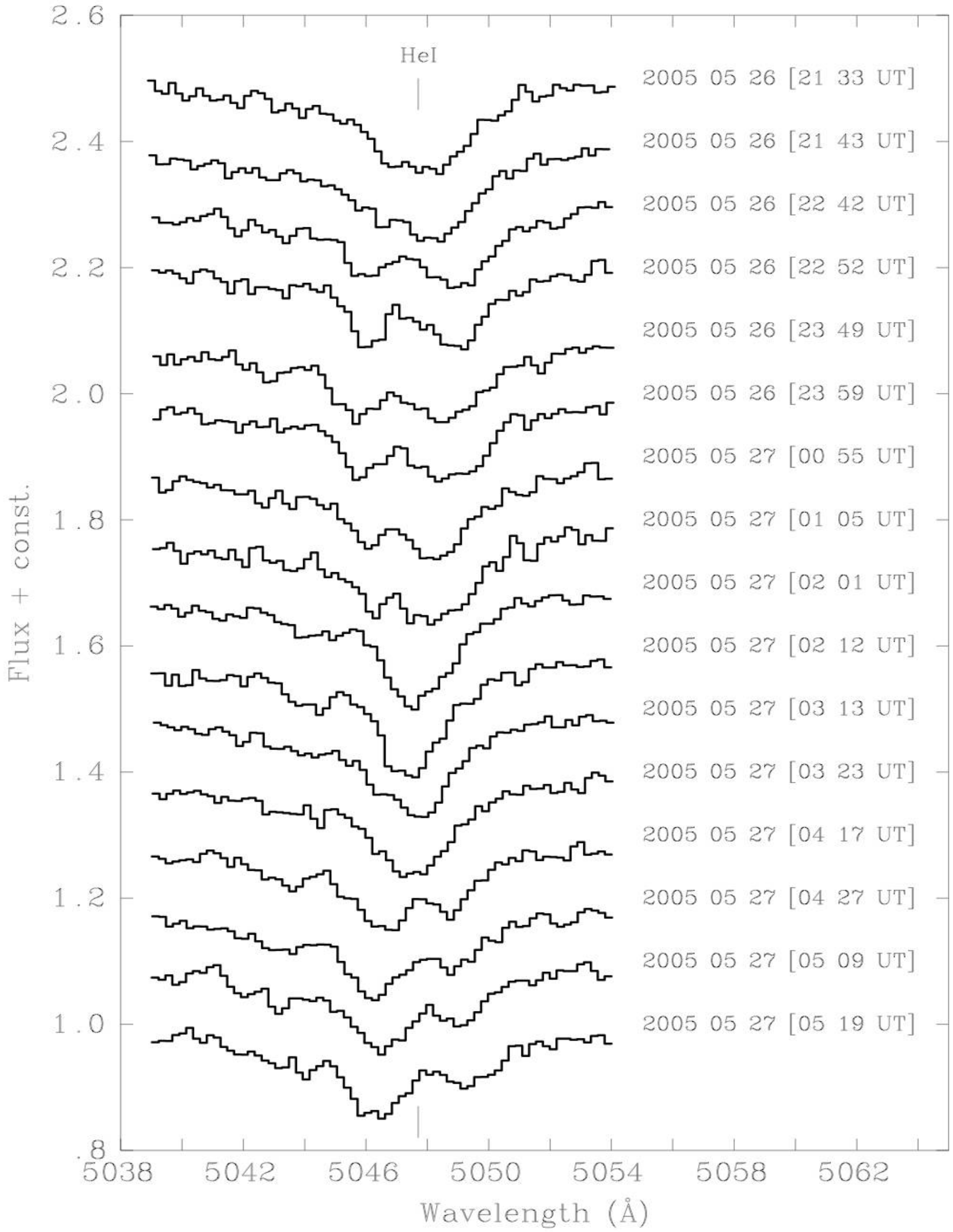


Fig 3. Blue spectra

Short section of blue spectra of PG1544+488 obtained in 2005 May with WHT/ISIS showing the line doubling of a neutral helium line

The hotter primary seen on the left in the bottom most spectrum has a much stronger line than the cooler secondary



Radial velocity from optical spectra

- We selected the strong neutral helium 6678A line for measuring radial velocities. Red spectra obtained with ISIS in 2003, 2004 and 2005 were obtained with the same instrumental setup. All spectra were also reduced in exactly the same way using standard IRAF routines

- Since the two components were visible in most instances, we chose to directly measure their individual radial velocities. This was done by fitting a broad Lorentzian function to the wings of the lines and two Gaussian functions to the line cores. Near conjunction, when the two components are not well separated we fixed the full width half maxima (FWHM) of the two Gaussian functions to measure the radial velocity

- Using the two radial velocity curves we were able to measure the period of the system (P = 0.50 days). Given that PG1544+488 is a short period binary, the orbit is likely to be circular. The circular orbital solution is plotted in Fig. 4 and the parameters are listed in Table 1

Fig 4. Orbital solution

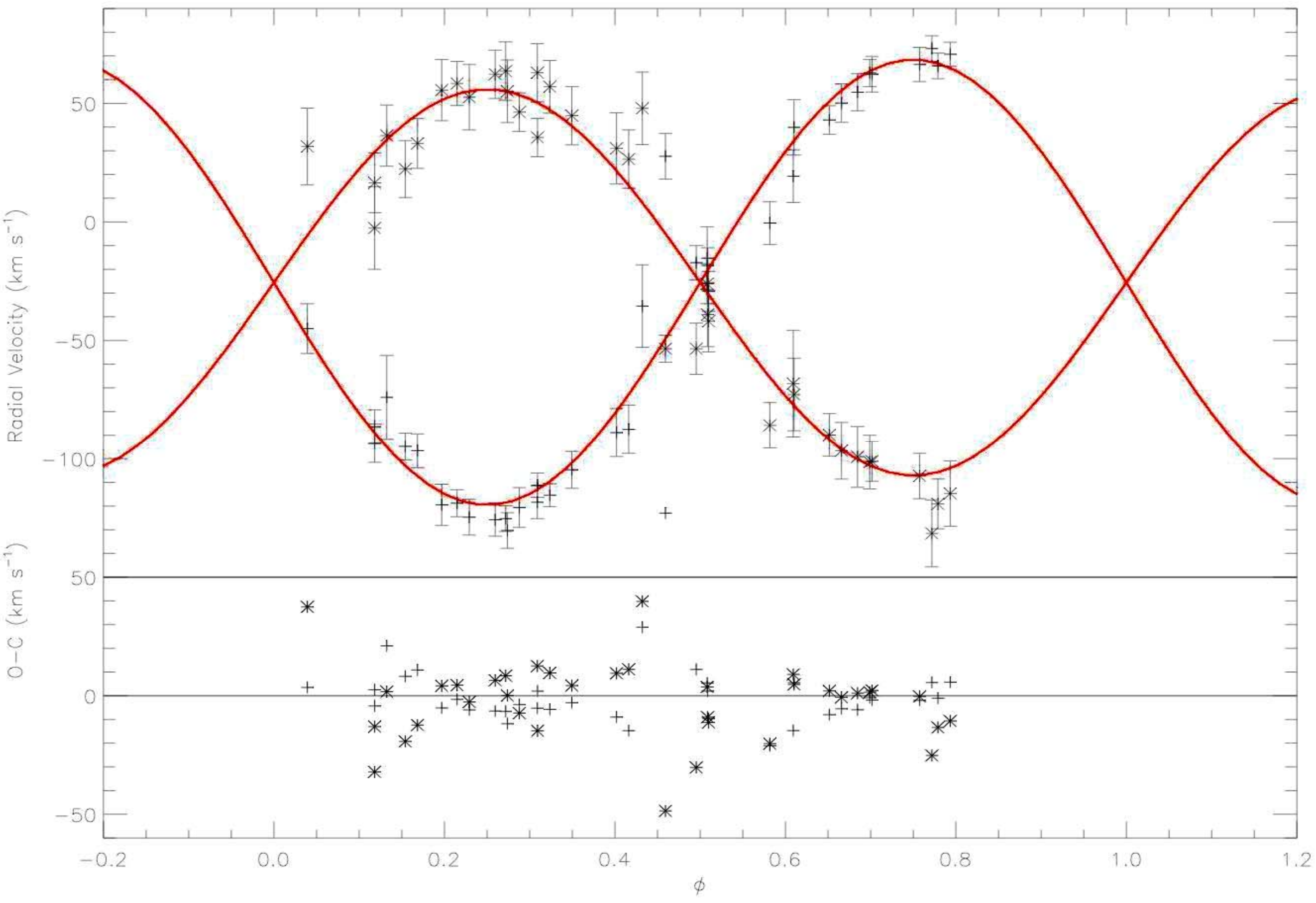


Table 1. Orbital parameters

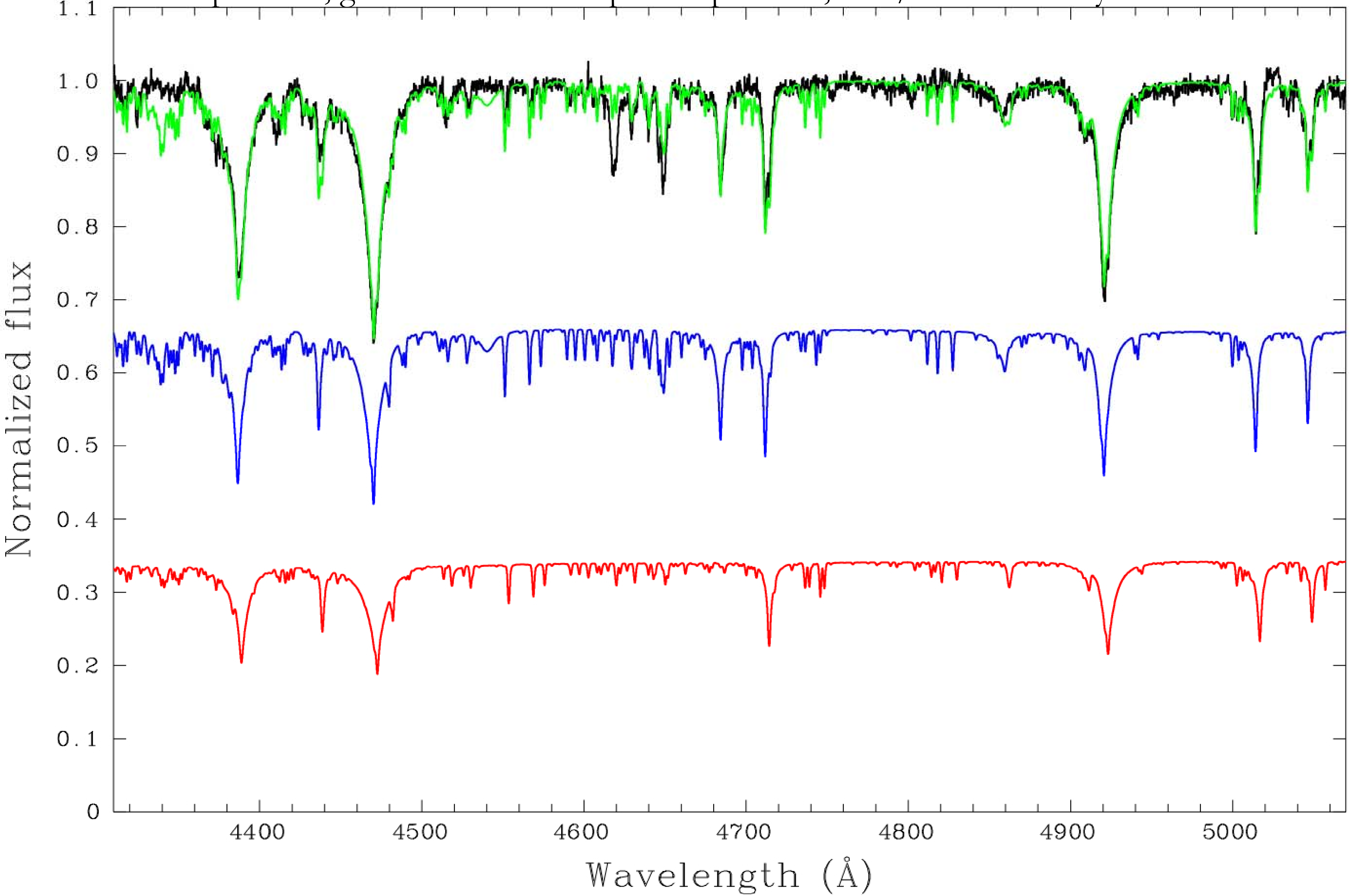
P	0.496 ± 0.001	days
γ	-25.6 ± 4	km s^{-1}
K_1	81.5 ± 4	km s^{-1}
K_2	94.0 ± 5	km s^{-1}
q	1.2 ± 0.2	
$a\sin i$	1.72 ± 0.13	R_o
$M_1\sin^3 i$	0.148 ± 0.021	M_o
$M_2\sin^3 i$	0.128 ± 0.011	M_o

Atmospheric physical parameters

- Over 40 spectra of PG1544+488 were obtained over three years with WHT/ISIS
- Physical parameters: effective temperature (T_{eff}), surface gravity ($\log g$) and helium abundance (n_{He}) were measured from 11 spectra where the two components were well resolved using a grid of metal line blanketed LTE models using χ^2 minimization
- The computer code SFIT2 was used for the minimization. It simultaneously solves for all three physical parameters for both stars and the radius ratio
- An example best fit solution is shown in Fig. 4 for illustration. The individual components (scaled by the radius ratio) are also shown
- Note that the projected rotational velocity could not be measured due to the moderate resolution of the observed spectra hence $v\sin i$ was kept fixed at 0 km s^{-1} for both stars

Fig 5. Example best fit solution

black – observed spectrum, green – best fit composite spectrum, blue/red – scaled synthetic model



Physical parameters cont…

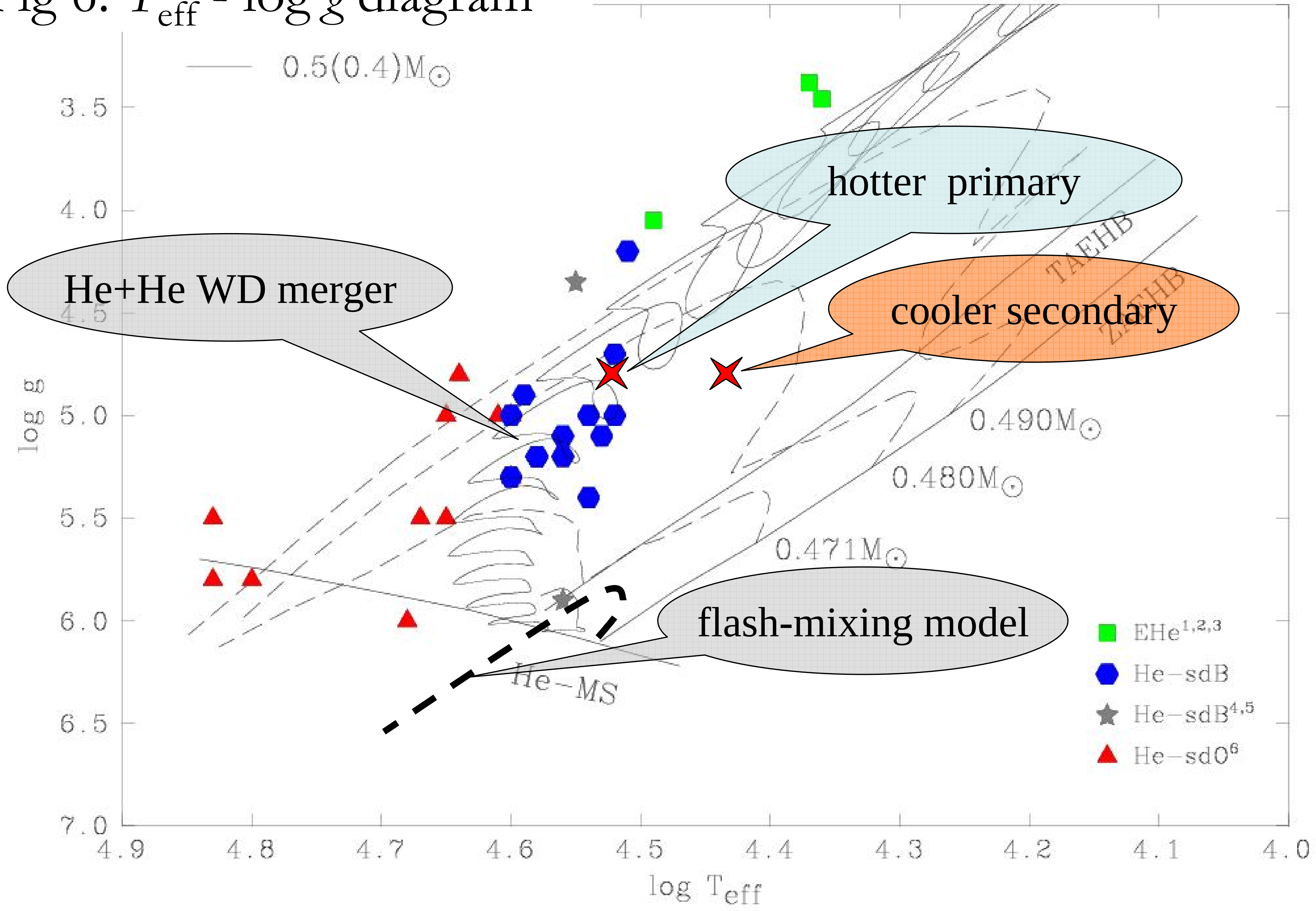
- Since the Balmer lines in the optical blue spectra of PG1544+488 are very weak, both components must be extremely helium-rich. The helium abundance by number was thus fixed at 0.99 for both stars

- Each of the 11 spectra of PG1544+488 were independently analysed as follows. Keeping the helium abundance fixed, SFIT2 was initialized. The parameters measured from the χ^2 minimization were effective temperate and surface gravity for each star and the radius ratio. Radial velocity was also a free parameter

- For each spectrum the mass-ratio was calculated using the radius ratio and the surface gravities of the two stars. The mean physical parameters are listed below

	Primary	Secondary	M_2/M_1
T_{eff} (K)	33000 ± 1300	25800 ± 900	1.08 ± 0.60
$\log g$ (cgs)	4.9 ± 0.3	4.9 ± 0.3	

Fig 6. T_{eff} - log g diagram



Evolution

- The evolution of two helium-rich subdwarfs in PG1544+488 poses a serious challenge for the existing evolutionary models

- Since the system is a close binary, it is highly unlikely that both have been produced by white dwarf mergers

- The two stars are also too luminous to have undergone flash mixing

- This leaves us with the possibility that the two stars are post common envelope objects opening the possibility of an alternate scenario for the formation of extremely helium-rich subdwarfs by close binary evolution

- It would be interesting to check whether such an evolution would result in carbon enrichment

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